

LATENCY CONTROL CIRCUIT AND METHOD OF LATENCY CONTROL

RELATED APPLICATION DATA

This is a continuation-in-part of Application No. 10/283,124 filed October 30, 2002; the contents of which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

[0001] Fig. 1 illustrates a block diagram of a prior art memory device. The memory device 100 includes a memory cell array 110, a clock synchronizing circuit block 120, a read command path block 130, a data output buffer 140, a mode register 150 and a latency circuit 160. In operation, data is written into the memory cell array 110 and read out from the memory cell array 110. If a read command is asserted to the memory device 100, data is read out from the memory cell array 110 according to an externally received address. A buffer 116 receives and temporarily stores the address. A row decoder 112 receives the stored address and decodes a row address of the memory cell array 110 from the address. A column decoder 114 receives the stored address and decodes a column address of the memory cell array 110 from the address. The memory cell array 110 outputs the data addressed by the row and column addresses. The data output buffer 140 receives the data output from the memory cell array 110, and outputs the data based on a latency signal from the latency circuit 160 and an internal data output clock signal CLKDQ.

[0002] The clock synchronizing circuit block 120 generates the data output clock signal CLKDQ based on an external clock signal ECLK.

The external clock signal ECLK serves as a reference clock signal for

most commands of the memory device 100. Specifically, most commands are asserted to the memory device 100 in synchronization with the external clock signal ECLK. As shown in Fig. 1, the clock synchronizing circuit block 120 is a delay locked loop (DLL) circuit.

5 The DLL circuit 120 includes a variable delay 122, a data output buffer replica 124 and a phase detector 126. The DLL circuit 120 is a well known circuit such as described in U.S. Patent No. 5,614,855; and therefore, will not be described in detail. The DLL circuit 120 generates the data output clock signal CLKDQ as a phase lead version
10 of the external clock ECLK. Namely, the data output clock signal CLKDQ has the same frequency as the external clock ECLK, but the pulses of the data output clock signal CLKDQ precede the pulses of the external clock signal ECLK by a data output time tSAC. The data output time is a measurement of the time it takes the data output
15 buffer 140 to output data. Accordingly, the DLL circuit 120 causes data to be output from the data output buffer 140 in synchronization with the external clock ECLK.

[0003] The read command path block 130 receives the read command and the external clock signal ECLK. An internal clock
20 generator 132 receives the external clock signal ECLK and generates an internal clock signal PCLK from the external clock signal ECLK. Specifically, the internal clock signal PCLK is a buffered version of the external clock signal ECLK. Therefore, the internal clock signal PCLK has the same frequency as the external clock signal ECLK and the
25 level of the internal clock signal PCLK swing is a CMOS level (VSS-VCC) buffered signal delayed from the external clock signal ECLK. The internal clock signal PCLK is used to control peripheral circuits (not shown) such as data sense amplifiers, data multiplexers, etc., in the memory device 100. A read command buffer 134 in the read

command path block 130 receives the read command and the internal clock signal PCLK. The read command buffer 134 inputs the read command synchronized with the internal clock signal PCLK, and outputs an internal read signal PREAD, which is supplied to the latency circuit 160.

[0004] The memory device 100 has several modes of operation. The mode register 150 stores a mode register set (MRS) command asserted to the memory device 100. The MRS command indicates the mode of the memory device 100. CAS latency information is determined by the MRS command. The CAS latency information indicates the CAS latency mode, which is the number of clock cycles of the external clock signal ECLK that should occur between the receipt of a read command or column address until data is output by the memory device 100. Stated another way, data is output from the memory device in a CAS latency number of clock cycles after receipt of the read command (a column address being asserted together with the read command).

[0005] The latency circuit 160 receives the CAS latency information from the mode register 150 and generates a latency signal such that the data output buffer 140 is enabled to output the data according to the desired CAS latency. More specifically, the data output buffer 140 outputs the stored data in response to the data output clock signal CLKDQ while the latency signal is enabled.

[0006] Fig. 2 illustrates a prior art latency circuit 160. As shown, the latency circuit 160 includes first, second and third D-flip flops 215, 225 and 235 connected in cascade. Each D-flip flop receives the data output clock signal CLKDQ at its clock input. The internal read signal PREAD is supplied to the D input of the first D-flip flop 215. The internal read signal PREAD and Q output of each of the first-third

D-flip flops 215, 225 and 235 are respectively connected to first-fourth switches 210, 220, 230 and 240. The first-fourth switches 210, 220, 230 and 240 are respectively controlled by a CAS latency indicator CL1, CL2, CL3 and CL4 decoded from the CAS latency information.

- 5 Namely, the CAS latency information is N bits that indicate the CAS latency mode. The N bits are decoded by a simple logic decoder (not shown) to produce the CAS latency indicators CL1 – CL4 associated with each CAS latency mode. As will be appreciated, the CAS latency indicator for the activated CAS latency mode will be, for example, logic
- 10 high, while the other CAS latency indicators will be logic low. The output of the first-fourth switches 210, 220, 230 and 240 serve as the latency signal. In operation, only one of the CAS latency modes will be logic high; therefore, only one of the first-fourth switches 210, 220, 230 and 240 will transfer a signal for output as the latency signal.
- 15 For example, when the CAS latency is 1, CL1 is logic high and turns on first switch 210. At this time, the other CAS latency indicators CL2, CL3, and CL4 are logic low. The internal read signal is then transferred as the latency signal via the first switch 210. When the CAS latency is two (i.e., CL equals 2), then CL2 is logic high, while
- 20 CL1, CL3 and CL4 are logic low. Thus, the internal read signal PREAD is transferred as the latency signal via the first D-flip flop 215 and the second switch 220. The first D-flip flop 215 is triggered by the data output clock signal CLKDQ and delays the internal read signal PREAD being output as the latency signal by about one clock
- 25 cycle. The operation when the CAS latency is three or four is similar to that discussed above with respect to the CAS latency of two, and therefore will not be repeated for the sake of brevity. Additionally, it will be understood that CAS latencies greater than four could be handled by the addition of more D-flip flops and switches.

[0007] Fig. 3A illustrates a timing diagram of the read operation when the CAS latency is 1. At a clock cycle C0, a read command 310 is asserted, and an internal read signal PREAD is generated by the read command path block 130 after an internal delay time tREAD.

5 The latency signal is then enabled in response to the internal read signal PREAD as discussed above with respect to Fig. 2. As further shown in Fig. 3A, the DLL circuit 120 generates the data output clock signal CLKDQ such that the rising edge of the data output clock signal CLKDQ precedes the rising edge of the external clock signal ECLK by
10 a period of time tSAC, where the time period tSAC equals the delay between enabling data output from the data output buffer 140 and the actual output of data from the memory device 100. As further discussed above with respect to Fig. 1, the data output buffer 140 outputs data when triggered by the data output clock signal CLKDQ
15 only when the latency signal is enabled. Because the CAS latency has been set to 1 in this example, the latency signal is enabled prior to receipt of the data output clock signal CLKDQ. As a result, data is output from the memory device 100 in synchronization with the first clock pulse C1 of the external clock signal ECLK following the clock
20 pulse C0 of the external clock signal ECLK when the read command 310 was received. The time delays tREAD and tSAC are internal delays set according to current process technology. Minimizing these delays improves the timing margin as to when the latency signal must be enabled before receipt of the data output clock signal CLKDQ. As
25 the frequency of operation increases (i.e., the frequency of the external clock signal ECLK increases), the period between clock pulses of the external clock signal ECLK decreases. This reduces the timing margin for supplying the latency signal. Consequently, above a certain operating frequency, the latency signal enables after the data output

clock signal CLKDQ, and the data is no longer output at the desired CAS latency. This results in a data read operation failure.

[0008] Fig. 3B illustrates another example of where the operation frequency is low enough such that a proper data read operation takes

5 place for a CAS latency of 2. However, Fig. 3C shows the operation of

the memory device 100 during a high frequency operation, wherein a data read operation failure takes place. As shown in this example,

tREAD plus tSAC is greater than the period tCC of the external clock signal ECLK such that the internal read signal PREAD is asserted

10 after the rising edge of a pulse CDQ1 of the data output clock signal CLKDQ. The latency signal thus becomes enabled after a pulse CDQ4 of the data output clock signal CLKDQ for the desired CAS latency. In

the example of Fig. 3C, the desired CAS latency is 4, and as is shown, data is output according to a CAS latency of 5 instead of a CAS

15 latency of 4. As a result, a data read operation failure takes place.

SUMMARY OF THE INVENTION

[0009] The memory device according to the present invention includes a memory cell array from which data is read. Read data is stored in an output buffer, which outputs data based on a latency signal generated in accordance with the desired CAS latency of the

20 memory device. The memory device includes a latency circuit that permits a desired CAS latency of the memory device to be achieved without read operation error even when the memory device is operating at high frequency.

[0010] More specifically, the latency circuit selectively associates at

25 least one transfer signal with at least one sampling signal based on the desired CAS latency to create a desired timing relationship between the associated sampling and transfer signals. Read

information is stored by the latency circuit in accordance with at least one of the sampling signals, and the latency signal is generated based on the transfer signal associated with the sampling signal used in storing the read information.

- 5 [0011] The arrangement and methodology of the latency circuit in the present invention allows for pointing or identifying a point in time as to when the memory cell array of the memory device is being read, and for pointing or identifying a point in time when to generate the latency signal with respect to the first pointer. By establishing the
10 relationship between the first and second pointers based on the desired CAS latency, a read operation according to the desired CAS latency is achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

- [0012] The present invention will become more fully understood from the detailed description given below and the accompanying drawings,
15 wherein like elements are represented by like reference numerals, which are given by way of illustration only and thus are not limitative of the present invention and wherein:

- [0013] Fig. 1 illustrates a block diagram of a prior art memory device;
- 20 [0014] Fig. 2 illustrates a prior art latency circuit;
- [0015] Fig. 3A illustrates a timing diagram of the read operation when the CAS latency is 1 for the memory device of Fig. 1;
- [0016] Fig. 3B illustrates a timing diagram of the read operation when the CAS latency is 2 for the memory device of Fig. 1;
- 25 [0017] Fig. 3C illustrates a timing diagram of the read operation when the CAS latency is 4 for the memory device of Fig. 1;

[0018] Figs. 4A-4C illustrate exemplary embodiments of the memory device according to the present invention;

[0019] Fig. 5 illustrates an embodiment of the latency signal generator in Figs. 4A-4C;

5 **[0020]** Fig. 6 illustrates an embodiment of the sample clock signal generator and the transfer signal generator of Fig. 5;

[0021] Fig. 7 illustrates an embodiment of the master clock generator in Figs. 4A-4C;

10 **[0022]** Fig. 8 illustrates the operation of the master clock generator in Fig. 7;

[0023] Figs. 9A-9T illustrate the waveforms of the signals generated by or received by the memory device of Figs. 4A, 4B or 4C having a latency signal generator as illustrated in Fig. 5;

15 **[0024]** Fig. 10A illustrates an embodiment of the multiplexers in Fig. 5;

[0025] Fig. 10B illustrates the mapping of transfer signals to output transfer clock signals for the embodiment of the multiplexers illustrated in Fig. 10A;

20 **[0026]** Fig. 11 illustrates another embodiment of the latency signal generator in Figs. 4A-4C;

[0027] Figs. 12A-12S illustrate the waveforms of the signals generated by or received by the memory device of Figs. 4A, 4B or 4C having a latency signal generator as illustrated in Fig. 11;

25 **[0028]** Fig. 13A illustrates an embodiment of the multiplexers in Fig. 11;

[0029] Fig. 13B illustrates the mapping of sampling signals to output sampling clock signals for the embodiment of the multiplexers illustrated in Fig. 13A;

[0030] Fig. 14 illustrates another embodiment of the latency signal generator in Figs. 4A-4C;

[0031] Fig. 15 illustrates an embodiment of the sample clock signal generator and the transfer signal generator of Fig. 14;

5 [0032] Fig. 16 illustrates tables for CAS latency modes two-five that demonstrate which of the first-fourth transfer clock signals TCLK1-TCLK4 and which of the first-fourth sampling clock signals SCLK1-SCLK4 become active for each CAS latency mode in the embodiment of Fig. 15;

10 [0033] Figs. 17A-17S illustrate the waveforms of the signals generated by or received by the memory device of Figs. 4A, 4B or 4C having a latency signal generator as illustrated in Fig. 14 when the CAS latency mode is four; and

[0034] Figs. 18 and 19 illustrates waveforms as shown in Fig. 17 for
15 CAS latency modes three and five, respectively.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0035] Fig. 4A illustrates an embodiment of the memory device according to the present invention. As shown, the memory device 400 includes a memory cell array 110, a clock synchronizing circuit block
20 120, a read command path block 130, a data output buffer 140, a mode register 150, and a latency circuit 500. Like reference numerals have been used to designate like components between the memory device 400 and the prior art memory device 100 described in the Background of the Invention section. Accordingly, a description of
25 these same components will not be repeated for the sake of brevity.

[0036] Fig. 4B illustrates one embodiment of the latency circuit 500 in greater detail. As shown, the latency circuit 500 includes a latency signal generator 502 generating the latency signal based on the data

output clock CLKDQ, a master clock signal PCLKD, the internal read signal PREAD, and the CAS latency information. A read command path block replica 460 in the latency circuit 500 generates the master clock signal PCLKD based on a buffered version of the data output clock signal CLKDQ, which is generated by the data output buffer replica 124 in the clock synchronizing circuit block 120. As such, the latency circuit 500 has been illustrated as sharing the data output buffer replica 124 with the clock synchronizing circuit block 120. The operation of the read command path block replica 460 and the latency signal generator 502 will be described in greater detail below after the discussion of a second embodiment of the latency circuit 500.

[0037] Fig. 4C illustrates a second embodiment of the latency circuit 500. In this embodiment, the latency circuit 500 does not include the data output buffer replica 124 or the read command path block replica 460. Instead, as shown in Fig. 4C, these elements are external to the latency circuit 500.

[0038] Next, the read command path block replica 460 and the latency signal generator 502 will be described in detail.

[0039] The read command path block replica 460 includes an internal clock generator replica 462 that receives a buffered version of the data output clock signal CLKDQ from the data output buffer replica 124. The data output buffer replica 124 replicates the output delay of the data output buffer 140. Accordingly, the buffered clock signal CLKF is a delayed version of the data output clock signal CLKDQ. The internal clock generator replica 462 is a replica of the internal clock generator 132, and generates a replica internal clock signal PCLKR. A master clock generator 700 receives the internal clock signal PCLK and the replica internal clock signal PCLKR and generates a master clock signal PCLKD.

[0040] Fig. 7 illustrates an embodiment of the master clock generator 700. As shown, an inverter 704 receives the replica internal clock signal PCLKR. The output of the inverter 704 controls the operation of a PMOS transistor 706, which is connected in series with an NMOS transistor 708 between a power supply voltage VCC and a reference or ground voltage VSS. The operation of the NMOS transistor 708 is controlled by a reset signal. An enable signal is generated at the node connecting the PMOS transistor 706 and the NMOS transistor 708. This enable signal is latched by a latch 720, which is comprised of inverters 722 and 724 connected in a loop configuration to the enable signal node EN. An AND gate 710 receives the enable signal and a delayed internal clock signal PCLK2. A delay unit 702 receives and delays the internal clock signal PCLK to generate the delayed internal clock signal PCLK2. The period of the delay substantially equals the period of time to generate the enable signal based on the replica internal clock signal PCLKR. The output of the AND gate 710 serves as the master clock signal PCLKD.

[0041] Fig. 8 illustrates the operation of the master clock generator 700. As shown, when the reset signal is enabled, the NMOS transistor 708 pulls the enable signal to logic low. As a result, the AND gate 710 generates a logic low master clock signal PCLKD. When the reset signal is no longer enabled, the replica internal clock signal PCLKR controls the state of the enable signal such that at the rising edge of the replica internal clock signal PCLKR, the enable signal transitions to a logic high state. As a result, the AND gate 710 will output the delayed internal clock signal PCLK2 as the master clock signal PCLKD. The replica internal clock signal PCLKR is generated from output of the DLL circuit 120. As a result, the replica internal clock signal PCLKR experiences some jitter, which decreases the frequency

performance of the memory device. By using the replica internal clock signal PCLKR to enable the master clock signal PCLKD and by outputting the master clock signal PCLKD as a delayed version of the internal clock signal PCLK, which has not experienced such jitter, the master clock generator 700 generates a master clock signal PCLKD without jitter. Furthermore, because the internal clock signal PCLK is used as an internal clock signal for many of the peripheral circuits in the memory device 400, the internal clock signal PCLK experiences a large load. By contrast, the master clock signal PCLKD is not as loaded, and therefore can be used as a clock signal of the latency circuit 500 as described in detail below.

[0042] Fig. 5 illustrates an exemplary embodiment of the latency signal generator 502. As shown, the latency signal generator 502 includes a sampling signal generator 510 generating first-fourth sampling signals S1-S4 that, in this embodiment, serve as first-fourth sampling clock signals SCLK1-SCLK4, respectively. Accordingly, in this embodiment, the sampling signal generator 510 serves as a sampling clock signal generator, which generates the sampling clock signals based on the master clock signal PCLKD. Similarly, a transfer signal generator 550 generates first-fourth transfer signals T1-T4 based on the data output clock signal CLKDQ. The sampling clock signal generator 510 and the transfer signal generator 550 include first and second ring shift registers 520 and 560, respectively, such as illustrated in Fig. 6.

[0043] As shown in Fig. 6, first-fourth D-flip flops 521-524 are connected in cascade. First-fourth AND gates 525-528 have one input connected to a Q output of the first-fourth D-flip flops 521-524, respectively. The other input of the first-fourth AND gates 525-528 and the clock inputs of the first-fourth D-flip flops 521-524 receive the

master clock signal PCLKD in the case of the sampling clock signal generator 510 or the data output clock signal CLKDQ in the case of the transfer signal generator 550. Also as shown, the Q output of the fourth and final D-flip flop 524 is fed to the D input of the first D-flip flop 521. The outputs of the first-fourth AND gates 525-528 supply the first-fourth sampling clock signals SCLK1-SCLK4 in the case of the sampling clock signal generator 510 or supply the first-fourth transfer signals T1-T4 in the case of the transfer signal generator 550. Lastly, the reset inputs of the first-fourth D-flip flops 521-524 receive the reset signal. The first D-flip flop 521 is a settable D-flip flop and the second-fourth D-flip flops 522-524 are resettable D-flip flops. The reset signal enables the pre-setting of the shift register such that the first D-flip flop is SET(logic high state) and the others are RESET(logic low state).

[0044] The logic high signal will load into the first D-flip flop 521 on the rising edge of the received clock signal, and this pulse will be transferred to the second-fourth D-flip flops 522-524 as each clock signal pulse is received. Accordingly, when the logic high signal resides in a respective one of the first-fourth D-flip flops 521-524, the corresponding one of the first-fourth AND gates 525-528 outputs a logic high pulse in synchronization with the received clock signal. This operation is illustrated in Figs. 9A, 9D, and 9E-9M. Fig. 9A illustrates the reset signal, Figs. 9D and 9E illustrate the data output clock signal CLKDQ and the master clock signal PCLKD, respectively. Figs. 9F-9I illustrate the first-fourth transfer signals T1-T4, and Figs. 9J-9M illustrate the first-fourth sampling clock signals SCLK1-SCLK4.

[0045] Returning to Fig. 5, the latency signal generator 502 further includes a read information storage unit 530. The read information storage unit 530 includes first-fourth latches 531-534. The first-

fourth latches 531-534 receive the first-fourth sampling clock signals SCLK1-SCLK4, respectively, at their clock inputs, receive the internal read signal PREAD at their latch input, have their reset input connected to the reset signal, and generate first-fourth output signals LS1-LS4, respectively. Each latch will latch the internal read signal PREAD on the rising edge of the respectively received sampling clock signal. This operation is illustrated in Figs. 9N-9R.

[0046] Fig. 9N illustrates the internal read signal PREAD, and Figs. 9O-9R illustrate the output signals LS1-LS4. As shown, if the PREAD signal is logic high when the third sampling clock SCLK3 illustrated in Fig. 9L transitions to logic high, the third latch 533 latches the logic high PREAD signal and generates a logic high output signal LS3.

[0047] Fig. 5 further illustrates that the first-fourth output signals LS1-LS4 are received by first-fourth switches 535-538, respectively.

The outputs of the switches are each connected to an output latch 539. Whether the first-fourth switches 535-538 transfer the respectively received first-fourth output signals LS1-LS4 to the output latch 539 depends upon the state of the transfer signal received by that switch as will be described in more detail below. For example, if the third switch 537 receives a logic high transfer signal when the third output signal LS3 is logic high as shown in Fig. 9Q, then the logic high output signal LS3 is transferred to the latch 539 and a logic high latency signal is generated as shown in Fig. 9S. As with the first-fourth latches 531-534, the reset input of the output latch 539 is also connected to the reset signal, and the state thereof is reset to zero when the reset signal is enabled.

[0048] The latency signal generator 502 illustrated in Fig. 5 further includes a mapping unit 540. The mapping unit 540 includes first-fourth multiplexers 541-544, which are four input by one output

multiplexers. Each of the first-fourth multiplexers 541-544 receives each of the first-fourth transfer signals T1-T4, and outputs one of the first-fourth transfer signals T1-T4 to a respective one of the first-fourth switches 535-538 in the read information storage unit 530.

- 5 The selection made by each of the first-fourth multiplexers 541-544 is controlled by the CAS latency information as discussed in greater detail below.

[0049] The latency signal generator 502 illustrated in Fig. 5 supports four CAS latency modes as evidenced by the four D-flip flops, latches, switches and multiplexers in the circuits forming the latency signal generator 502. However, the present invention is not limited to supporting four CAS latency modes, and could support greater or fewer CAS latency modes by increasing or decreasing the number of D-flip flops, latches, switches and multiplexers forming the latency circuit 500.

[0050] Fig. 10A illustrates an embodiment of the first-fourth multiplexers 541-544 wherein the four CAS latency modes supported are modes 2-5. As shown, each of the first-fourth multiplexers 541-544 maps one of the first-fourth transfer signals T1-T4 into an output transfer signal TCLK1-TCLK4, respectively. Here, the N bits forming the CAS latency information may be used as the selection signal of the first-fourth multiplexers 541-544 as illustrated in Fig. 10A.

Alternatively, as illustrated in Fig. 10A as well, gates in each of the first-fourth multiplexers 541-544 are controlled by a respective CAS latency indicator CL2-CL5. The CAS latency indicators are decoded from the CAS latency information in the manner discussed in the Background of the Invention section. Each gate selectively transfers one of the transfer signals T1-T4 as a transfer clock signal TCLK1-TCLK4 based on the respective CAS latency indicator. Fig. 10B

illustrates which of the first-fourth transfer signals T1-T4 is mapped to the first-fourth output transfer signals TCLK1-TCLK4 for the embodiment of the multiplexers illustrated in Fig. 10A.

[0051] Next, a high frequency operation of the memory device

5 according to the embodiment illustrated in one of Figs. 4A-4C and Figs. 5, 6, 7, 10A and 10B will be described with respect to Figs. 9A-9T. Fig. 9A illustrates the reset signal. When enabled, the reset signal resets the DLL circuit 120, the read command path block 130, the master clock generator 700 and the latency circuit 500. As a
10 result, as shown in Figs. 9D-9M and 9S, the data output clock signal CLKDQ, the master clock signal PCLKD, the first-fourth transfer signals T1-T4, the first-fourth sampling clock signals SCLK1-SCLK4, and the latency signal are reset to a logic low or zero state.

[0052] Fig. 9B illustrates the external clock signal ECLK. Pulses of

15 the external clock signal ECLK have been labeled 1, 2, 3, etc., in order to provide an understanding of the relationship between the external clock signal ECLK and both the data output clock signal CLKDQ and the master clock signal PCLKD. As shown in Fig. 9D, after a first internal delay period t_{RS1} , the DLL circuit 120 begins generating the
20 output clock signal CLKDQ. As shown in Fig. 9E, after a second internal delay period t_{RS2} , the master clock generator 700 begins generating the master clock signal PCLKD. As was described previously, the output data clock signal CLKDQ precedes the external clock signal ECLK by a time period t_{SAC} . The clock pulses of the
25 output data clock signal CLKDQ have also been numbered 1, 2, 3, etc., to show the relationship between these clock signal pulses and the clock signal pulses of the external clock signal ECLK. The master clock generator 700 begins generating the master clock signal PCLKD, a time period equal to t_{SAC} plus t_{READ} after the output data clock

signal CLKDQ is generated. The time period tSAC has been discussed in detail above. The time period tREAD is the period of time between receipt of the read command and generation of the internal read signal PREAD by the read command buffer 134. The pulses of the master
5 clock signal PCLKD illustrated in Fig. 9E have also been labeled 1, 2, 3, etc., to show the correspondence between these clock signal pulses and the clock signal pulses of the data output clock signal CLKDQ and the external clock signal ECLK. Accordingly, it will be understood that the reset operation establishes the timing relationships between
10 these clock signals.

[0053] As shown in Figs. 9F-9I with respect to Fig. 9D, once the transfer signal generator 550 begins receiving clock signal pulses of the output data clock signal CLKDQ, pulses of the first-fourth transfer signals T1-T4 are generated. As demonstrated by Figs. 9F-9I, each
15 transfer signal has a frequency equal to the frequency of the external clock signal ECLK divided by the maximum number of supported CAS latency modes. Namely, it will be appreciated that the frequency of the transfer signals is determined by the number of D-flip flops in the second ring shift register 560.

[0054] Figs. 9J-9M with respect to Fig. 9E illustrate that the first-fourth sampling clock signals SCLK1-SCLK4 are generated by the sampling clock signal generator 510 when the master clock generator 700 begins generating pulses of the master clock signal PCLKD. As with the transfer signals, the sampling clock signals also have a
25 frequency that is equal to the frequency of the external clock signal ECLK divided by the maximum number of supported CAS latency modes. Namely, the frequency of the first-fourth sampling clock signals SCLK1-SCLK4 is determined by the number of D-flip flops in the first ring shift register 520.

[0055] The above discussed operation of the embodiment according to the present invention holds for any of the four possible CAS latency modes two-five, supported by this embodiment of the invention. Figs. 9F-9I include parentheticals that show which of the first-fourth transfer signals T1-T4 are mapped to the first-fourth output transfer signals TCLK1-TCLK4 when the CAS latency mode is 4. Also, Figs. 9O-9T illustrate the output signals LS1-LS4, the latency signal, and the data output from the memory device 400 when the CAS latency mode is 4 and a read command is received by the memory device 400 as illustrated in Fig. 9C.

[0056] As shown in Fig. 9C, in this operational example, the read command signal is received when clock signal pulse 3 of the external clock signal ECLK transitions to logic high. Consequently, as shown in Fig. 9N, the internal read signal PREAD is generated after an internal delay of tREAD, by the read command path block 130.

[0057] As shown in Figs. 9F-9I, when the CAS latency is 4, the first-fourth transfer signals T1-T4 are mapped by the mapping unit 540 to the second, third, fourth and first output signals TCLK2, TCLK3, TCLK4 and TCLK1. Stated another way, first-fourth switches 535-538 receive the fourth, first, second and third transfer signals T1-T4, respectively. As such, when the internal read signal PREAD transitions to logic high as shown in Fig. 9N, the third sampling clock signal SCLK3 causes the third latch 533 to latch the logic high PREAD signal. The other latches will have latched logic low PREAD. Accordingly, only the third output signal LS3 from the third latch 533 will have a logic high state as shown in Figs. 9O-9R.

[0058] Then, when the second transfer signal T2 transitions to logic high, the third switch 537 supplies a logic high signal to the output latch 539, which in turn supplies a logic high latency signal as shown

in Fig. 9S. Because the latency signal is logic high when the output data clock signal CLKDQ transitions high at pulse 7 of the output data clock signal CLKDQ, the memory device 400 will output data D1 as shown in Fig. 9T at the rising edge of pulse 7 of the external clock signal ECLK as shown in Fig. 9B. Accordingly, with the read command having been received during pulse 3 of the external clock signal ECLK and the data being output from the memory device 400 at pulse 7 of the external clock signal ECLK, a CAS latency of 4 is achieved for the high frequency operation shown in Fig. 9B. In this embodiment, a single data word is output; however, the present invention is not limited to this embodiment. Instead, by increasing the length of the read command, the number of data words output can be increased.

[0059] As will be appreciated, the mapping unit 540 selectively associates the transfer signals with the sampling clock signals based on the CAS latency to create a desired timing relationship between the sampling and transfer signals. This relationship then controls the time period between the receipt of a read command and the output of data by the memory device 400. More specifically, this relationship controls the time period between receipt of the internal read signal PREAD and the generation of the latency signal. Here, the sampling clock signals trigger the first-fourth latches 531-534 and thus serve to designate a point in time when the read command is received. The association of the transfer signals with the sampling clock signals then serves as a second pointer in time as to when the latency signal should be generated. Through this arrangement and methodology, read operation errors during high frequency operation are prevention.

[0060] Fig. 11 illustrates another embodiment of the latency signal generator 502 according to the present invention. As shown, the

latency signal generator 502 in this embodiment is the same as the embodiment of Fig. 5, except that the mapping unit 540 has been eliminated and a new mapping unit 1100 has been added. Also, the reset signal has been deleted, but only to simplify the description. In view of the above, only the differences between the embodiments of Figs. 11 and 5 will be described for the sake of brevity.

[0061] With the elimination of the mapping unit 540, the transfer signals T1-T4 generated by the transfer signal generator 550 are directly supplied to the first-fourth switches 535-538 as the first-fourth transfer clock signals TCLK1-TCLK4, respectively. Accordingly, in this embodiment, transfer signal generator 550 serves as a transfer clock signal generator.

[0062] The mapping unit 1100 maps the first-fourth sampling signals S1-S4 to the first-fourth latches 531-534 as the first-fourth sampling clock signals SCLK1-SCLK4. The mapping unit 1100 includes first-fourth multiplexers 1121-1124, which are four input by one output multiplexers, as shown in Fig. 13A. Each of the first-fourth multiplexers 1121-1124 receives each of the first-fourth sampling signals S1-S4, and outputs one of the first-fourth sampling signals S1-S4 to a respective one of the first-fourth latches 531-534 in the read information storage unit 530. The selection made by each of the first-fourth multiplexers 1121-1124 is controlled by the CAS latency information as shown in Fig. 13A.

[0063] The latency signal generator 502 illustrated in Fig. 11 supports four CAS latency modes as evidenced by the four D-flip flops, latches, switches and multiplexers in the circuits forming the latency signal generator 502. However, the present invention is not limited to supporting four CAS latency modes, and could support greater or fewer CAS latency modes by increasing or decreasing the number of

D-flip flops, latches, switches and multiplexers forming the latency signal generator 502.

[0064] Fig. 13A illustrates an embodiment of the first-fourth multiplexers 1121-1124 wherein the four CAS latency modes

5 supported are modes 2-5. As shown, each of the first-fourth multiplexers 1121-1124 maps one of the first-fourth sampling signals S1-S4 into a sampling clock signal SCLK1-SCLK4, respectively. Here, the N bits forming the CAS latency information may be used as the selection signal of the first-fourth multiplexers 1121-1124 as

10 illustrated in Fig. 10A. Alternatively, as illustrated in Fig. 10A as well, gates in each of the first-fourth multiplexers 1121-1124 are controlled by a respective CAS latency indicator CL2-CL5. The CAS latency indicators are decoded from the CAS latency information in the manner discussed in the Background of the Invention section. Each
15 gate selectively transfers one of the sampling signals S1-S4 as a sampling clock signal SCLK1-SCLK4 based on the respective CAS latency indicator. Fig. 13B illustrates which of the first-fourth sampling signals S1-S4 is mapped to the first-fourth sampling clock signals SCLK1-SCLK4 for the embodiment of the multiplexers
20 illustrated in Fig. 13A.

[0065] Figs. 12A-12S illustrate the high frequency operation of the memory device according to the embodiment illustrated in one of Figs. 4A-4C and Figs. 11, 6, 7, 13A and 13B for the CAS latency mode of four. Figs. 12A-12S correspond to Figs. 9B-9E, 9N, 9F-9M, and 9O-
25 9T, respectively. Accordingly, Figs. 12A-12S will not be described in detail for the sake of brevity.

[0066] Fig. 14 illustrates a further exemplary embodiment of the latency signal generator 502. As shown, the latency signal generator 502 in this embodiment includes a sampling clock signal generator

1410, which selectively generates the first-fourth sampling clocks SCLK1-SCLK4 based on the CAS latency information, and a transfer clock signal generator 1420, which selectively generates the first-fourth transfer clocks TCLK1-TCLK4 based on the CAS latency

5 information. The generated sampling clock and transfer clock signals are supplied to the read information storage unit 530 described in detail above with respect to the embodiment of Fig. 5. Accordingly, only the sampling clock signal generator 1410 and the transfer clock signal generator 1420 will be described in detail below. Also, as with
10 the embodiment of Fig. 11, the reset signal has been deleted, but only to simplify the description.

[0067] The sampling clock signal generator 1410 and the transfer clock signal generator 1420 include a ring shifter cooperatively associated with control logic such as illustrated in Fig. 15 to

15 selectively generate the respective clock signals. As shown in Fig. 15, first-fourth D-flip flops 1431-1434 are connected in cascade with first-third control logic units 1441-1443 disposed between the first and second, second and third and third and fourth D-flip flops, respectively.

20 **[0068]** Each of the first-third control logic units 1441-1443 includes an inverter 1451 receiving and inverting the Q output of the previous D-flip flop. A NOR gate 1453 receives the output of the inverter and a respective CAS latency indicator decoded in the well-known manner from the CAS latency information. As shown in Fig. 15, the CAS

25 latency indicators CL2-CL4 for the second-fourth CAS latency modes are respectively supplied as an input to the NOR gate 1453 in the first-third control logic units 1441-1443. The output of the NOR gate 1453 is supplied to D input of the next D-flip flop. The clock inputs of the first-fourth D-flip flops 1431-1434 receive the master clock signal

PCLKD in the case of the sampling clock signal generator 1410 or the data output clock signal CLKDQ in the case of the transfer clock signal generator 1420.

[0069] The Q outputs of the first-fourth D-flip flops 1431-1434 are received by first-fourth switches 1461-1464. The first-fourth switches 1461-1464 selectively connect the Q outputs of the first-fourth D-flip flops 1431-1434 with the D input of the first D-flip flop 1431 based on the respectively received CAS latency indicators CL2-CL5 for the second-fifth CAS latency modes. The Q outputs of the first-fourth D-flip flops supply the first-fourth sampling clock signals SCLK1-SCLK4 in the case of the sampling clock signal generator 1410 or supply the first-fourth transfer clock signals TCLK1-TCLK4 in the case of the transfer clock signal generator 1420. Lastly, while not shown, the reset inputs of the first-fourth D-flip flops 1431-1434 receive the reset signal. The first -fourth D-flip flops 1431-1434 are resettable D-flip flops. The reset signal enables the pre-setting of the shift register such that the first-fourth D-flip flops are reset (logic low state).

Additional control logic well-known in the art (not shown) is connected to the D input of the first D-flip flop 1431 to load a logic "1" (logic high state) into the first D-flip flop 1431.

[0070] The logic high signal will load into the first D-flip flop 1431 on the rising edge of the received clock signal (PCLKD or CLKDQ), and this pulse will be transferred to the second-fourth D-flip flops 1432-1433 depending on the CAS latency information as each clock signal pulse is received. When the logic high signal resides in a respective one of the first-fourth D-flip flops 1431-1434, the corresponding sampling clock signal/transfer clock signal is active.

[0071] When the first-third control logic units 1441-1443 receive a logic low CAS latency indicator, the first-third control logic units

1441-1443 transfer the Q output from the previous D-flip flop to the D input of the next D-flip flop. When the first-third control logic units 1441-1443 receive a logic high CAS latency indicator, the first-third control logic units 1441-1443 output a logic low state to the next D-flip flop regardless of the Q output of the previous D-flip flop.

[0072] As will be appreciated, the logic high state loaded into the first D-flip flop 1431 will only be transferred to a next position in the ring shift register selectively formed by the first-fourth D-flip flops 1431-1434 based on the CAS latency information. Thus, the CAS latency information controls the number of active sampling clock signals and transfer clock signals.

[0073] For example, if the CAS latency information indicates CAS latency mode 4, then the CAS latency indicators CL2 and CL3 are logic low. Accordingly, the logic high state loaded into the first D-flip flop 1431 will be transferred to the second D-flop flop 1432 and then the third D-flip flop 1433 in synchronization with the received clock signal (PCLKD/CLKDQ). But, this logic high state will not be transferred from the third control logic unit 1443 to the fourth D-flop flop 1434 by third control logic unit 1443 because the third control logic unit 1443 receives a logic high CAS latency indicator CL4. As a result, the first-third sampling clock signal SCLK1-SCLK3 and the first-third transfer clock signals TCLK1-TCLK3 will be activated, but not the fourth sampling clock signal SCLK4 or the fourth transfer clock signal TCLK4.

[0074] This operation is illustrated in Figs. 17A, 17C-D and 17F-M. Fig. 17A illustrates the external clock signal ECLK and Figs. 17C-D illustrates the data output clock signal CLKDQ and the master clock signal PCLKD generated from the external clock signal ECLK. Figs. 17F-17I illustrate the first-fourth transfer clock signals TCLK1-TCLK4,

and Figs. 17J-17M illustrates the first-fourth sampling clock signals SCLK1-SCLK4 when the CAS latency mode is 4.

[0075] As mentioned above, the CAS latency indicators CL2-CL5 also respectively control operation of the first-fourth switches 1461-1464.

5 When the first-fourth switches 1461-1464 receive a logic high CAS latency indicator, the first-fourth switches 1461-1464 connect the respectively received Q output from the first-fourth D-flip flops 1431-1434 with the D input of the first D-flip flop 1431. For example, when the CAS latency information indicates a CAS latency mode of 4, then
10 the CAS latency indicator CL4 is a logic high state, and only the third switch 1463 closes. This connects the Q output of the third D-flip flop 1433 to the D input of the first D-flip flop 1431. As discussed above, the logic high state loaded into the first D-flip flop 1431 will only propagate up to the third D-flip flop 1433 when the CAS latency mode
15 is 4. Accordingly, the first-fourth switches 1461-1464 and the first-third control logic units 1441-1443 form control logic selectively configuring a ring shifter having a length dependent on the CAS latency information.

[0076] Fig. 16 illustrates tables for CAS latency modes two-five that
20 demonstrate which of the first-fourth transfer clock signals TCLK1-TCLK4 and which of the first-fourth sampling clock signals SCLK1-SCLK4 become active for each CAS latency mode.

[0077] Next, a high frequency operation of the memory device according to the embodiment illustrated in Figs. 4A, B or C and Figs.
25 14-15 will be described with respect to Figs. 17A-17S. Fig. 17A illustrates the external clock signal ECLK. Pulses of the external clock signal ECLK have been labeled 1, 2, 3, etc., in order to provide an understanding of the relationship between the external clock signal ECLK and both the data output clock signal CLKDQ and the master

clock signal PCLKD. As was described previously, the output data clock signal CLKDQ shown in Fig. 17C precedes the external clock signal ECLK by a time period tSAC. The clock pulses of the output data clock signal CLKDQ have also been numbered 1, 2, 3, etc., to show the relationship between these clock signal pulses and the clock signal pulses of the external clock signal ECLK. As also discussed above, the master clock generator 700 begins generating the master clock signal PCLKD, a time period equal to tSAC plus tREAD after the output data clock signal CLKDQ is generated as shown in Fig. 17D. As shown by Figs. 17B and 17E, the internal read command PREAD is generated a time period tREAD after receiving the read command. The pulses of the master clock signal PCLKD illustrated in Fig. 17D have also been labeled 1, 2, 3, etc., to show the correspondence between these clock signal pulses and the clock signal pulses of the data output clock signal CLKDQ and the external clock signal ECLK. It will be understood from the description of the previous embodiments, that the reset operation aids in establishing the timing relationships between these clock signals.

[0078] As shown in Figs. 17F-17H with respect to Fig. 17C, once the transfer clock signal generator 1420 begins receiving clock signal pulses of the output data clock signal CLKDQ, pulses of the first-third transfer clock signals TCLK1-TCLK3 are generated. For the reasons described in detail above and as shown by Fig. 17I, because the CAS latency is four, the transfer clock signal generator 1420 does not activate the fourth transfer clock signal TCLK4. As demonstrated by Figs. 17F-17H, each of the active first-third transfer clock signals has a frequency equal to the frequency of the external clock signal ECLK divided by one less than the CAS latency mode. Namely, it will be appreciated that the frequency of the transfer clock signals is

determined by the length of ring shift register configured by the control logic in the transfer clock signal generator 1420 based on the CAS latency mode.

[0079] Figs. 17J-17L with respect to Fig. 17D illustrate that the first-

5 third sampling clock signals SCLK1-SCLK3 are generated by the sampling clock signal generator 1410 in synchronization with the pulses of the master clock signal PCLKD. For the reasons described in detail above and as shown by Fig. 17M, because the CAS latency is four, the sampling clock signal generator 1410 does not activate the
10 fourth sampling clock signal SCLK4. As with the transfer clock signals, the sampling clock signals also have a frequency that is equal to the frequency of the external clock signal ECLK divided by one less than the CAS latency mode. Namely, the frequency of the activated first-third sampling clock signals SCLK1-SCLK3 is determined by the
15 length of ring shift register configured by the control logic in the sampling clock signal generator 1410 based on the CAS latency mode.

[0080] Figs. 17N-17S illustrate the output signals LS1-LS4, the latency signal, and the data output from the memory device 400 when the CAS latency mode is 4 and a read command is received by the
20 memory device 400 as illustrated in Fig. 17B.

[0081] As shown in Fig. 17B, in this operational example, the read command signal is received when clock signal pulse zero of the external clock signal ECLK transitions to logic high. Consequently, as shown in Fig. 17E, the internal read signal PREAD is generated after
25 an internal delay of t_{READ} , by the read command path block 130.

When the internal read signal PREAD transitions to logic high as shown in Fig. 17E, the first sampling clock signal SCLK1 causes the first latch 531 to latch the logic high PREAD signal. The other latches will have latched logic low PREAD. Accordingly, only the first output

signal LS1 from the third latch 531 will have a logic high state as shown in Figs. 17N-17Q.

[0082] Then, when the first transfer clock signal TCLK1 transitions to logic high, the first switch 535 supplies a logic high signal to the output latch 539, which in turn supplies a logic high latency signal as shown in Fig. 17R. Because the latency signal is logic high when the output data clock signal CLKDQ transitions high at pulse 4 of the output data clock signal CLKDQ, the memory device 400 will output data D0 as shown in Fig. 9S at the rising edge of pulse 4 of the external clock signal ECLK as shown in Fig. 9A. Accordingly, a CAS latency of 4 is achieved for the high frequency operation shown in Fig. 17A. In this embodiment, a single data word is output; however, the present invention is not limited to this embodiment. Instead, by increasing the length of the read command, the number of data words output can be increased.

[0083] Figs. 18 and 19 illustrate timing diagrams corresponding to the timing diagrams in Fig. 17 for CAS latency modes three and five, respectively. As the timing diagrams of Figs. 18 and 19 are readily understood from the description of the timing diagrams in Fig. 17, the timing diagrams in Figs. 18 and 19 will not be described in detail for the sake of brevity.

[0084] The latency signal generator 502 illustrated in Fig. 14 supports four CAS latency modes as evidenced by the four D-flip flops, latches, switches and multiplexers in the circuits forming the latency signal generator 502. However, the present invention is not limited to supporting four CAS latency modes, and could support greater or fewer CAS latency modes by increasing or decreasing the number of D-flip flops, latches, switches and multiplexers forming the latency circuit 500.

[0085] As will be appreciated, the sampling clock signal generator 1410 and the transfer clock signal generator 1420 selectively activate the sampling and transfer clock signals and control the frequency of the activated sampling and transfer clock signals based on the CAS latency to create a desired timing relationship between the sampling and transfer clock signals. This relationship then controls the time period between the receipt of a read command and the output of data by the memory device 400. More specifically, this relationship controls the time period between receipt of the internal read signal PREAD and the generation of the latency signal. As with previous embodiments, the sampling clock signals trigger the first-fourth latches 531-534 and thus serve to designate a point in time when the read command is received. The association of the transfer clock signals with the sampling clock signals then serves as a second pointer in time as to when the latency signal should be generated. Through this arrangement and methodology, read operation errors during high frequency operation are prevention.

[0086] The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.